Protocol

Impact of Climatic and Environmental Conditions on Prehospital Emergency Medical Dispatches in Germany: Protocol for an Exploratory, Population-Based Observational Study

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Abstract

Background: Extreme temperatures and other climatic stressors are increasingly affecting population health, even in temperate regions such as Germany. Previous studies have demonstrated associations between extreme heat, cold temperatures, and health indicators, including emergency department visits and mortality. However, most analyses rely on coarse meteorological data and hospital-based outcomes, limiting insights into fine-scale spatial variability and prehospital emergency responses. Prehospital emergency medical dispatches (PHEMD) data offer a unique opportunity to capture acute, real-time health effects of climatic and environmental conditions at high temporal resolution.

Objective: This study examines the association between climatic and environmental conditions and PHEMD use in 2 metropolitan regions in northern Germany. It will assess nonlinear temperature-response relationships, temporal lags, spatial and subgroup variation, and the added value of high-resolution vs station-based exposure assignment.

Methods: This is an exploratory, retrospective, population-based observational study using anonymized PHEMD data from the metropolitan regions of Hanover and Brunswick and their surrounding rural areas. PHEMD records will be linked to meteorological measurements and high-resolution urban microclimate data. Associations between climatic conditions and PHEMD use will be analyzed using quasi-Poisson regression with distributed lag nonlinear model structures. The main temporal analyses will use daily mean temperature and lags of 0 to 6 days, with longer lag periods of up to 14 days

examined for cold-related effects. Models will account for temporal trends, seasonality, weekdays, public holidays, and, where appropriate, air pollution. Geographic information system–based maps will visualize the spatial distribution of effects.

Results: Study funding began in July 2025. As of November 2026, acquisition and harmonization of emergency medical service and meteorological data are ongoing. The study dataset will include data through December 2030, with the final data export planned thereafter. All analyses are expected to be completed and the resulting manuscripts submitted for publication by May 2031.

Conclusions: This study uses high-resolution environmental data and PHEMD records to examine climate-related emergency medical demand in northern Germany. By linking microclimate information with dispatch data, it aims to improve the understanding of spatial and temporal patterns beyond conventional approaches. The findings may support more targeted heat-health preparedness, improve emergency service planning, and inform local climate adaptation strategies.

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Introduction

Background

Extreme temperatures have become a growing public health concern in Germany, where recent decades have shown a steady rise in mean temperatures, an increasing number of hot days, and more frequent multiday heat waves [1,2]. These climatic shifts have been linked to substantial increases in heat-related morbidity and mortality, particularly among older adults [2,3] and individuals with chronic cardiovascular or respiratory conditions [1,4,5]. Similar patterns have been observed across Europe and other temperate regions, where large multicountry studies demonstrate a nonlinear association between temperature and health events, with marked increases above region-specific threshold temperatures [6-8].

In addition to mortality, an expanding body of evidence shows that both heat and cold contribute to higher rates of emergency department visits [9,10], ambulance dispatches [3], and hospital admissions [11-13]. Periods of extreme heat and cold are linked to increases in acute health events, often showing lag effects [14-16]. These patterns are influenced by multiple factors such as air pollution, humidity, and local microclimatic conditions [17-19]. Prehospital emergency medical dispatches (PHEMD) data are particularly valuable in this context because they capture acute events in near real time and reflect early population-level responses to temperature stress. Studies have reported increases in PHEMD demand during heat waves, especially for cardiovascular, respiratory, and dehydration-related events [20,21].

Germany has implemented the national heat health warning system, which issues forecasts and alerts based on the perceived temperature concept developed by the German Meteorological Service [22]. Although the heat health warning system supports risk communication and preparedness, evaluations have shown variable effectiveness in reducing mortality during heat episodes across regions, and localized analyses at finer spatial scales remain limited [23]. Urban areas in particular are affected by microclimatic variability driven by land cover, building density, and the urban heat island effect, yet most epidemiological studies rely on coarse meteorological data that do not reflect fine-scale spatial differences [24-27].

Despite substantial progress, important evidence gaps remain. Threshold temperatures, lag structures, and vulnerable population groups vary across studies, and little is known about high-resolution spatial patterns of microclimate-sensitive PHEMD use. Linking geocoded PHEMD data with detailed environmental and meteorologic information offers a unique opportunity to quantify temperature-related health risks more precisely, identify susceptible areas within cities, and support local adaptation and emergency preparedness strategies.

This study addresses these gaps by integrating PHEMD data from 2 metropolitan regions in northern Germany with high-resolution microclimate datasets. This approach enables a comprehensive assessment of temperature-related PHEMD use across spatial, temporal, and demographic dimensions.

Objective

This study aims to explore how climatic and environmental conditions are associated with PHEMD use in 2 regions in northern Germany, encompassing both densely populated urban centers and surrounding rural areas. The goal is to characterize how temperature, humidity, air quality, and local microclimatic variation relate to the frequency, distribution, and characteristics of PHEMD missions.

Specifically, the study seeks to (1) describe and quantify the exposure-response relationships between temperature measures and PHEMD use; (2) characterize temperature, humidity, and air quality ranges associated with increases in PHEMD demand; (3) analyze temporal patterns, including lag effects across short- and medium-term periods; (4) assess spatial variability by linking geocoded PHEMD records with high-resolution microclimate data; and (5) investigate demographic and population-level characteristics that may influence microclimate-sensitive PHEMD use.

The study is exploratory and aims to generate high-resolution, region-specific epidemiologic evidence that can support heat-health preparedness, climate adaptation planning, and PHEMD resource management.

Methods

Study Design and Analytical Framework

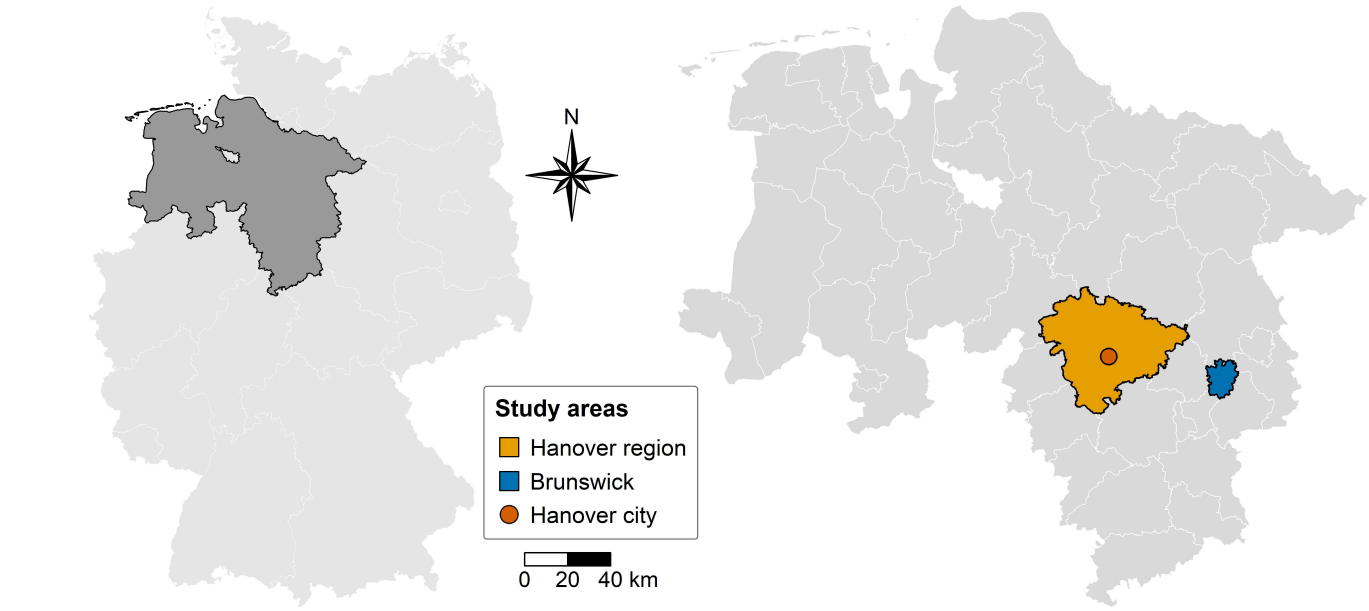
This is an exploratory, retrospective, population-based observational study using anonymized secondary PHEMD data from 3 emergency medical service areas in the Hanover and Brunswick metropolitan regions linked with meteorological and environmental datasets. Depending on the research question, ecological, time-series, and spatial models will be used to examine temporal and spatial associations between climatic conditions and PHEMD use. Retrospective PHEMD data will be requested from each provider from the introduction of electronic documentation through 2031; the exact start year will depend on provider-specific digitization timelines and historical data availability. No intervention or individual follow-up is involved.

At the time of protocol preparation, the provider-specific PHEMD datasets were not yet fully available, and the microclimate monitoring network was still being established. This exploratory protocol therefore defines the overarching analytical framework, while preliminary analyses will be used to assess data structure, completeness, and quality and to develop procedures for data merging, harmonization, quality control, and linkage; any resulting methodological refinements will be documented transparently.

Study Area

The study area comprises the Hanover and Brunswick metropolitan regions in the federal state of Lower Saxony, northern Germany [28]. These regions include both densely populated urban environments and extensive surrounding suburban and rural areas, providing substantial variation in population density, land use, and microclimatic characteristics relevant for climate-health analyses. The geographic location of the study regions within Germany and Lower Saxony is illustrated in Figure 1.

Figure 1. Geographic location of the study regions in the German federal state of Lower Saxony, Germany: (A) location of Lower Saxony within Germany; (B) detailed view of the Hanover and Brunswick metropolitan regions. The scale bar refers to Panel B.



Hanover City

The City of Hanover, the capital of Lower Saxony, is located at 52.37° N, 9.72° E and covers 204 km² with approximately 540,000 inhabitants (2023). The urban fabric includes densely built districts with limited vegetation, contributing to a measurable urban heat island effect [29]. Large green areas, such as the Eilenriede forest and the Maschsee lake [30], introduce notable intra-urban microclimatic variability.

Hanover Region

The Hanover Region covers approximately 2290 km² and includes 21 municipalities with a combined population of about 1.2 million residents. The region is situated on the North German Plain and is characterized by a mixture of urban, suburban, and agricultural landscapes.

Brunswick

Brunswick, located at 52.26° N, 10.53° E, covers 192.7 km² and has a population of approximately 250,000 residents (2024). The city is embedded in a wider area of peri-urban and rural municipalities dominated by agricultural land use

and lower population density. Brunswick forms part of the Hanover-Brunswick-Göttingen-Wolfsburg metropolitan region, one of Germany's officially designated metropolitan areas [31].

These regions lie within the temperate climate zone (Cfb after Köppen-Geiger) with maritime influence, characterized by warm summers, mild winters, and modest topographic variation (50-130 m above sea level). This combination of urban and rural settings, along with heterogeneous land-use patterns and microclimate conditions, results in substantial spatial variability in thermal exposure across the study area.

Data Collection

PHEMD Records

The study routinely collected PHEMD records from the rescue service providers in the City of Hanover, the Hanover Region, and the City of Brunswick. While documentation systems differ slightly between these areas, all PHEMD services are based on the DIVI (Deutsche Interdisziplinäre Vereinigung für Intensiv- und Notfallmedizin [German Interdisciplinary Association for Intensive Care and Emergency Medicine]) emergency documentation standard, which provides a structured and comprehensive framework for prehospital data collection [32,33]. The DIVI protocol includes standardized fields for operational characteristics, patient assessment (eg, age and sex), vital signs, neurological status (Glasgow Coma Scale [34]), suspected diagnoses, severity classifications (eg, National Advisory Committee for Aeronautics [NACA] [35]), and documented interventions. This uniform structure supports consistent extraction of core clinical indicators, even though local digital implementations vary in detail and completeness.

Across all participating providers, the PHEMD datasets include time-stamped information for each PHEMD record.

- Dispatch and operational information, including alarm categories, mission types, and complete operational timelines from dispatch to handover.
- Spatial information, based on address fields or geocoordinates. It is derived from mission location fields (eg, dispatch address or geocoordinates), which refer to the location of the emergency event rather than personal residential information. The type and precision of spatial information vary between providers depending on local data protection policies; data may therefore range from exact geocoordinates to coarser location identifiers.
- Clinical assessments, such as presenting symptoms, vital signs, neurological findings (eg, Glasgow Coma Scale [34]), and suspected diagnoses, documented in structured fields.
- Severity assessments, including NACA scores and other routinely collected indicators of clinical urgency.
- Interventions and treatment measures, including airway management, ventilation support, circulatory interventions, medication administration, and resuscitation procedures.
- Mission outcomes, including transport decisions, receiving facility types, and other operational circumstances.

While all services rely on the DIVI standard, variations in digital documentation systems and local coding practices mean that specific field availability, granularity, and completeness will differ between providers.

All datasets provided for this study are fully anonymized. This applies to both patients and PHEMD personnel, as no identifying information such as names, residential addresses, insurance information, staff IDs, or comparable identifiers is included.

Climate and Weather Data

Climate and environmental data in this study combine measurements from meteorological monitoring networks with microscale meteorological model simulations to represent both regional weather conditions and local microclimate patterns across Hanover and Brunswick, as well as the smaller peri-urban settlements Wedemark and Cremlingen. The datasets include air temperature, humidity, solar radiation, and wind, as well as air pollutants that are relevant for heat and pollution-related health effects.

Regional microclimate information originates from established meteorological stations that continuously record air temperature, relative humidity, and related atmospheric variables (eg, wind speed and solar radiation) at regular intervals. These long-term measurements provide a stable basis for describing wider climatic conditions and for identifying periods of heat, cold, or rapid weather changes.

To capture the environmental conditions within the urban areas more accurately, additional data come from dense networks of research-grade and quality-controlled crowdsourced urban stations (eg, SenseCAP S1000 sensors). These instruments provide near-surface measurements of air and temperature, humidity, and solar radiation and help represent small-scale thermal comfort variations created by buildings, shading, vegetation, and street layout. Mobile measurements on bicycles or vehicles complement these data by documenting local differences in temperature and air quality along specific routes [36].

Air pollutant data include measurements of particulate matter (PM_{10} and $PM_{2.5}$), ultrafine particles, and CO_2. These pollutants vary strongly across urban environments and are influenced by traffic, ventilation, urban geometry, and thermal and atmospheric conditions.

In addition to measured data, high-resolution microclimate simulations provide spatially continuous information on thermal comfort and air pollutant distribution. These simulations incorporate land use patterns, building geometry, vegetation, and radiative processes and allow the representation of neighborhood-scale thermal and air quality conditions that cannot be captured by point measurements alone. They also generate pollutant fields using traffic activity patterns and atmospheric dispersion processes.

High-resolution urban microclimate simulations will be performed using the PALM (parallelized large-eddy simulation model) system [37]. PALM enables the simulation of a wide range of atmospheric, surface, and biometeorological variables beyond air temperature, humidity, and air pollutants. Depending on the specific research questions, model outputs may include wind fields, radiation fluxes, and human-biometeorological indices such as the Universal Thermal Climate Index. The selection of output variables will be guided by the study objectives and the relevance for health-related exposure assessment.

Traffic-related emissions used as input for air pollutant simulations will be derived from the MATSim (multi-agent transport simulation) framework [38], which provides temporally and spatially resolved emission estimates based on traffic activity patterns. In addition, agent-based pedestrian simulations implemented within the PALM model system will use origin-destination matrices derived from MATSim to represent human movement through the urban environment. These agents allow the estimation of individual-level exposure to atmospheric variables, including thermal conditions and air pollutants, along with realistic movement trajectories in outdoor environments. The temporal resolution of the simulated microclimate and environmental variables is flexible and will be adapted to the analytical requirements of the study.

Spatial resolution differs by data source and ranges from point-based station measurements to grid-based model outputs that resolve conditions at the neighborhood scale. Temporal resolution varies from continuous high-frequency recordings to hourly values produced by simulations.

The environmental datasets will not be combined into a single composite exposure measure. Long-term fixed-station measurements will provide the primary exposure series for the multiyear temporal analyses because they offer the most consistent temporal coverage. Urban sensor networks will be used to construct locally resolved exposure surfaces where sufficient spatial and temporal coverage is available. Mobile measurements will primarily serve as an independent validation source for these surfaces and will support the analysis of spatial variability. PALM outputs will provide physically consistent, spatially continuous exposure fields for selected periods and study areas and will be evaluated in embedded high-resolution analyses. Air pollutants will be examined as separate exposures and, where appropriate, as potential confounders.

Data Analysis

Climate Data and Definition of Extreme Events

All environmental records will be converted to a common time reference and harmonized with respect to units and temporal resolution. Source-specific quality-control procedures will be applied before aggregation, including the identification of duplicate records, implausible values, incomplete measurement intervals, and periods of sensor malfunction. Newly added urban sensors will be evaluated against reference sensors in parallel measurement campaigns before being installed in the study area, while crowd-sourced stations will be validated by mobile measurements, where possible. To capture extreme conditions, percentile-based thresholds will be derived separately for each region and station, and days exceeding these thresholds will be classified as hot or cold days.

PHEMD Records

PHEMD data will be aggregated into total daily counts for the main temporal analyses and into mission-specific daily counts for secondary analyses. Structured operational and clinical fields will be harmonized across providers using the DIVI standard. Free-text entries (eg, dispatch notes and symptom descriptions) will be categorized using locally deployed large language models (LLMs) and text-mining approaches, allowing identification of relevant themes such as heat-related complaints, respiratory deterioration, or dehydration.

Given the rapid development of the field, locally deployable LLMs and text-mining approaches available at the time of analysis will be tested and compared using a manually classified sample of free-text entries. Manual classification and evaluation will be conducted in collaboration with an experienced emergency medical services professional. Any prompt refinement or model adaptation will be conducted separately from the final evaluation. Performance against the manual classifications will be assessed using appropriate measures (eg, precision, recall, and F_1-scores), and discordant cases will be examined through error analyses (eg, review of false-positive and false-negative classifications). The selected approach, including the model and version, prompts, and relevant processing steps, will be documented to support reproducibility.

Location information (addresses, coordinates, or coarse spatial markers) will be processed where available to support spatial linkage. Depending on data availability, additional contextual sociodemographic indicators (eg, neighborhood-level population structure or socioeconomic characteristics) may be incorporated to support the interpretation of spatial patterns and potential confounding factors.

Spatial Exposure Assignment and Validation

Each PHEMD record will be linked to environmental exposure estimates using the event date and time and the most precise available incident location. For records with point coordinates, exposure values will be extracted from the corresponding spatial grid cell. Where only coarser spatial identifiers are available, exposure values will be aggregated over the corresponding spatial unit.

Spatially continuous exposure surfaces derived from monitoring data will be generated using candidate approaches including inverse distance weighting, kriging, regression-based methods [39], and selected machine-learning methods. These approaches will be evaluated independently of the PHEMD outcomes using spatially blocked or k-fold cross-validation. Selection will be based on mean absolute error, root mean squared error, mean bias, spatial coverage, and physical plausibility. Where measurements overlap in time

and space, mobile observations will provide an additional external validation dataset.

The best-performing approach for each exposure and study area will be selected for the main spatial exposure assignment before the epidemiological associations are estimated.

For selected periods and study areas, PALM-derived exposure fields will be linked to PHEMD records according to incident time and location. PALM will not replace the long-term station-based exposure series used in the main temporal analyses. Instead, PALM-derived values assigned to individual PHEMD records will be used as exposure variables in embedded spatial and spatiotemporal epidemiological analyses. Associations with PHEMD outcomes will be compared with those obtained using station-based or interpolated exposure assignments to assess the added value of high-resolution estimates of air temperature, thermal comfort, and air pollution. PALM outputs will be compared with fixed and mobile measurements during overlapping periods using the same validation metrics applied to the interpolation methods.

Modeling Framework

The main temporal analyses will examine the association between daily mean air temperature and total daily PHEMD counts using quasi-Poisson regression models incorporating distributed lag nonlinear model (DLNM) structures. These analyses will be conducted separately for each of the 3 participating emergency medical service areas to account for regional differences in exposure distributions, data availability, and documentation practices. Area-specific DLNM estimates will be combined, where appropriate, using a second-stage multivariate meta-analytic approach to derive an overall exposure-response association across the study regions. Daily mean air temperature will be used as the main thermal exposure, with lags from 0 to 6 days in the main specification; longer lag periods of up to 14 days will be examined for cold-related effects. Minimum and maximum temperatures and thermal comfort indices will be examined in secondary analyses.

Natural cubic splines will be used for both the exposure-response and lag-response functions. In the main specification, internal exposure knots will be placed at the 10th, 50th, and 90th percentiles of the temperature distribution, while lag knots will be placed at equally spaced values on the logarithmic lag scale. Models in the main temporal analyses will be adjusted for long-term trends and seasonality using smooth functions of calendar time, as well as for day of the week and public holidays. Humidity and air pollutants will be evaluated in additional adjusted models and sensitivity analyses, subject to data availability and collinearity.

Model fit and assumptions will be assessed using the dispersion parameter, residual deviance, quasi-Akaike information criterion, observed-vs-fitted values, and residual plots. Residual autocorrelation will be examined using the autocorrelation and partial autocorrelation functions, and potentially influential days will be assessed.

Multicollinearity among environmental variables will be assessed using correlation matrices and variance inflation factors. Closely related exposure measures, particularly thermal comfort indices and their underlying meteorological components, will generally be examined in separate model specifications rather than included simultaneously. Air pollutants will initially be examined individually and subsequently in multipollutant models where collinearity permits.

Days with incomplete PHEMD reporting due to data-transfer problems or provider outages will be excluded rather than treated as days without missions. Daily environmental metrics will be calculated only when at least 75% of the underlying measurements are available. Missing exposure values will not be imputed in the primary analyses. Missing individual-level variables, such as age or sex, will be reported and handled using available-case analyses in the corresponding subgroup models.

Where spatial information permits, generalized additive models (GAMs) may be used to explore spatial variability or microclimate-related differences. Spatial autocorrelation in area-level mission rates and model residuals will be assessed using the global Moran I based on an appropriate neighborhood or distance-based spatial weights matrix. Local indicators of spatial association may additionally be used to explore potential spatial clusters. If relevant residual spatial autocorrelation remains, it will be addressed using spatial smooth terms in generalized additive models or spatially structured regression models, depending on the spatial resolution and aggregation of the available data. Where available, sociodemographic and structural contextual variables, such as age, sex, care dependency status, or incident location characteristics, may be considered as potential confounders or effect modifiers. Their inclusion will depend on data access, spatial resolution, and completeness.

Where available, microclimate and environmental data will be analyzed at a temporal resolution higher than daily averages to capture intraday variation and diurnal exposure patterns. This allows exploration of short-term fluctuations and differences in the daily course of thermal and environmental conditions that may be relevant for acute PHEMD use. Aggregation to daily metrics will be applied where required for specific modeling approaches.

Model outputs will include relative risks and, where applicable, cumulative relative risks across lag periods, following conventions in climate-health epidemiology.

Geographic information system–based maps will be used to visualize the spatial distribution of potential patterns, including potential heat hotspots.

Sensitivity Analyses

Given the exploratory nature of the study and potential variation in data completeness across regions, prespecified sensitivity analyses will include alternative heat wave definitions, different temperature metrics, alternative lag structures for heat and cold effects, and models with and without adjustment for air pollution or humidity. Alternative

lag periods, knot numbers and positions, spline specifications, and degrees of freedom for temporal adjustment will be examined to assess the robustness of the DLNM results. Where the required exposure data are available, sensitivity analyses will compare nearest-station, selected interpolation-based, and PALM-based exposure assignments and will repeat spatial analyses after excluding records with only coarse location information. Alternative classification strategies for PHEMD free-text fields may also be evaluated, depending on data quality. Uncertainty related to exposure estimation and model specification will also be assessed, including interval-based uncertainty measures such as CIs or prediction intervals.

Ethical Considerations

Ethics approval was obtained from the Ethics Committee of the University Medical Center Göttingen (August 21, 2025; reference number 28/8/25). The study uses fully anonymized secondary data, and informed consent was waived.

Results

Study funding began on July 1, 2025. This study uses fully anonymized secondary data from emergency medical service records and meteorological monitoring systems, with no personally identifiable information processed. As of November 2026, data acquisition is ongoing, including agreements with emergency medical service providers and the collection and harmonization of meteorological and microclimate data. Heat wave definitions and exposure metrics are being explored and standardized. Routine data collection by the source providers continues independently of the study. The study dataset will include data through December 2030, with the final data export planned thereafter. Final analyses will follow completion of data acquisition and harmonization. All analyses are expected to be completed, and the resulting manuscripts submitted for publication by May 2031.

Discussion

Principal Findings and Comparison With Prior Work

This study protocol outlines an exploratory approach to investigate how climatic and environmental conditions, assessed at high spatial and temporal resolution, influence PHEMD use across 3 emergency medical service areas in 2 metropolitan regions in northern Germany. We anticipate nonlinear associations between ambient temperature and PHEMD use, with increasing demand during periods of high and potentially also low temperature. The analyses may identify ranges above or below which PHEMD demand begins to increase. However, these ranges are expected to vary according to the exposure metric, season, study region, and PHEMD category [40,41]. Associations with humidity and air quality may also be nonlinear, although their independent contributions may be difficult to distinguish because these environmental exposures are interrelated.

Heat-related increases in PHEMD demand are expected to occur predominantly on the day of exposure [20,21,40]. Associations with low temperatures may follow different temporal patterns and are therefore expected to emerge across different lag periods [41]. The magnitude and timing of these associations may also vary across clinical presentations and mission categories.

We further anticipate spatial variation that may be obscured by regional meteorological averages. Areas in which high thermal exposure coincides with dense development, extensive impervious surfaces, limited vegetation, or population-level vulnerability may show more pronounced increases in PHEMD demand [40,42,43]. However, these characteristics are unlikely to overlap consistently. Some areas with high thermal exposure may show little or no detectable excess PHEMD demand, whereas high absolute mission counts in other areas may primarily reflect population concentration or generally higher baseline demand.

The magnitude of the associations may also differ according to age, sex, care dependency, clinical presentation, and urban, suburban, or rural context [20,41,42]. Nevertheless, previous findings regarding susceptible groups have not been consistent. The absence of detectable differences in individual subgroups or locations would therefore also be informative and may reflect differences in exposure, adaptive capacity, mobility, or statistical precision.

Previous studies have linked high ambient temperatures and heat waves with increased ambulance and emergency medical service use, although estimated associations vary according to climate, heat wave definition, outcome classification, and temporal resolution [3,20]. German data from Frankfurt showed increased rescue service use during hot conditions [3]. A time series study from Würzburg similarly identified temperature ranges associated with increases in nontraumatic and cardiovascular ambulance dispatches. Associations persisted for up to 2 days, and spatial concentrations were observed in densely populated and built-up areas [40]. Evidence concerning low temperatures and PHEMD use remains less extensive, although recent findings also indicate increases in emergency ambulance demand during periods of extreme cold [41]. The assessment of both high and low temperatures across different lag periods may therefore extend the current evidence base.

Spatial studies from other settings have reported more heat-related PHEMD incidents in areas with greater impervious surface coverage, less vegetation, older populations, and socioeconomic disadvantage [42,43]. However, these studies have focused on explicitly heat-related diagnoses, aggregated events to administrative areas, or assigned exposure using meteorological stations or remotely sensed land surface temperature. Such approaches provide important evidence but may not fully represent the atmospheric conditions at the location and time of an emergency event.

The present study extends this work by integrating high-resolution measurements, dense environmental monitoring networks, spatially continuous PALM simulations, traffic and mobility information derived from

MATSim, and geocoded PHEMD records from 3 emergency medical service areas within 2 metropolitan regions. This combination may characterize local thermal and environmental exposures beyond conventional weather station coverage and reveal spatial variation in climate-sensitive emergency responses that is obscured by regional exposure averages. By directly comparing conventional weather-station-based and high-resolution exposure assignments, the study will determine whether fine-scale microclimate information materially changes estimated associations or primarily improves the identification of local patterns. This will provide direct evidence on the added value of high-resolution exposure assessment for identifying climate-sensitive PHEMD patterns beyond conventional approaches. Patterns identified in PHEMD use may also generate hypotheses for subsequent studies of other climate-sensitive health and health care utilization outcomes, such as emergency department visits or hospital admissions.

If relevant temporal and spatial patterns are identified, the findings may inform climate adaptation and urban resilience planning by indicating when, where, and among which population groups climate-related PHEMD demand is highest. This information could support the targeting of local heat-health measures and guide emergency service preparedness, including anticipatory staffing, vehicle allocation, and operational planning during extreme weather events. The comparison of conventional and high-resolution exposure assessments may additionally show whether fine-scale microclimate information provides operationally relevant added value for local planning.

Strengths and Limitations

A major strength of this study is the integration of complementary environmental data sources with routinely collected PHEMD information across urban, suburban, and rural settings. Temporal DLNM analyses, spatial models, alternative exposure assignments, and sensitivity analyses will allow the robustness of identified exposure-response relationships and lag structures to be assessed. The DIVI-based documentation systems provide a common structure for harmonizing core clinical and operational information across providers. Locally deployed LLMs and text mining methods may further improve outcome classification beyond structured fields, provided that their performance is evaluated against manually classified data.

Several limitations should be considered. PHEMD records are collected for operational rather than research purposes, and completeness, coding practices, and spatial precision may differ between providers and over time. Exposure assignment based on incident time and location may result in misclassification, particularly for indoor events or mobile populations. Neighborhood-level characteristics cannot be interpreted as individual patient characteristics, and high mission counts in densely populated areas cannot be interpreted as higher incidence or greater climate sensitivity without suitable population denominators. Accordingly, the study is designed to characterize population- and area-level associations rather than estimate individual-level causal effects.

Interpolated exposure surfaces and PALM simulations are subject to uncertainty related to sensor coverage, input data, model assumptions, spatiotemporal resolution, and validation, and they may only be available for selected periods. Moreover, the exploratory evaluation of multiple exposures, outcomes, subgroups, and spatial units increases the risk of chance findings, while sparse counts may limit the precision of local estimates. Findings will therefore be interpreted according to effect sizes, uncertainty, consistency across data sources and regions, and biological and operational plausibility. Identified exposure ranges will be regarded as region- and model-specific indicators rather than universal biological thresholds.

If reproducible exposure-response relationships, lag structures, or high-risk areas are identified, subsequent studies could evaluate their transferability to other regions and emergency medical service systems. Prospective research could then examine whether high-resolution environmental information improves short-term forecasting or supports targeted prevention and PHEMD resource planning before such information is incorporated into operational warning or dispatch systems.

Study findings will be disseminated through peer-reviewed publications and presentations at scientific conferences. Findings of relevance to emergency medical service planning and regional climate adaptation will also be shared with the participating emergency medical service providers and project partners.

Conclusions

This study will explore whether associations between climatic and environmental conditions and PHEMD use vary across time, space, and population groups in ways that may be relevant to PHEMD operations. It will examine exposure ranges and lag periods during which demand appears to increase and assess how thermal exposure, characteristics of the built environment, and population-level vulnerability overlap, including in areas where high thermal exposure is not accompanied by a detectable increase in PHEMD use. Patterns observed consistently across environmental data sources, analytical approaches, and study regions may help inform locally targeted heat-health preparedness, PHEMD resource planning, and climate adaptation.

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Generative AI Use

The authors used ChatGPT (OpenAI) to assist with language editing and proofreading and to improve the clarity and readability of the manuscript. The authors take full responsibility for the accuracy, originality, and integrity of all manuscript content, including all references and citations.

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Data Availability

The prehospital emergency medical dispatch data are not publicly available because they contain sensitive, routinely collected emergency medical services information. Access is subject to approval by the participating data providers and applicable data protection requirements. The specific data sources and observation periods will be reported for each analysis.

Authors' Contributions

Conceptualization: DS, DP, SB, BM, KN, SW, NK, FM
Funding acquisition: DP, SB, BM, KN, SW, NK, FM
Methodology: DS, FM
Writing – original draft: DS
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All authors read and approved the final version of the manuscript.

Conflicts of Interest

None declared.

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Abbreviations

DIVI: Deutsche Interdisziplinäre Vereinigung für Intensiv- und Notfallmedizin (German Interdisciplinary Association for Intensive Care and Emergency Medicine)
DLNM: distributed lag nonlinear model
GAM: generalized additive model
LLM: large language model
MATSim: multi-agent transport simulation
NACA: National Advisory Committee for Aeronautics
PALM: parallelized large-eddy simulation model
PHEMD: prehospital emergency medical dispatches

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